INTERIM REPORT:

Emissions Results from Clean Diesel Demonstration Program with CRT™ Particulate Filter at New York City Transit

New York State DEC
MTA NYCT
Johnson Matthey
Equilon
Corning
Environment Canada
RAD Energy

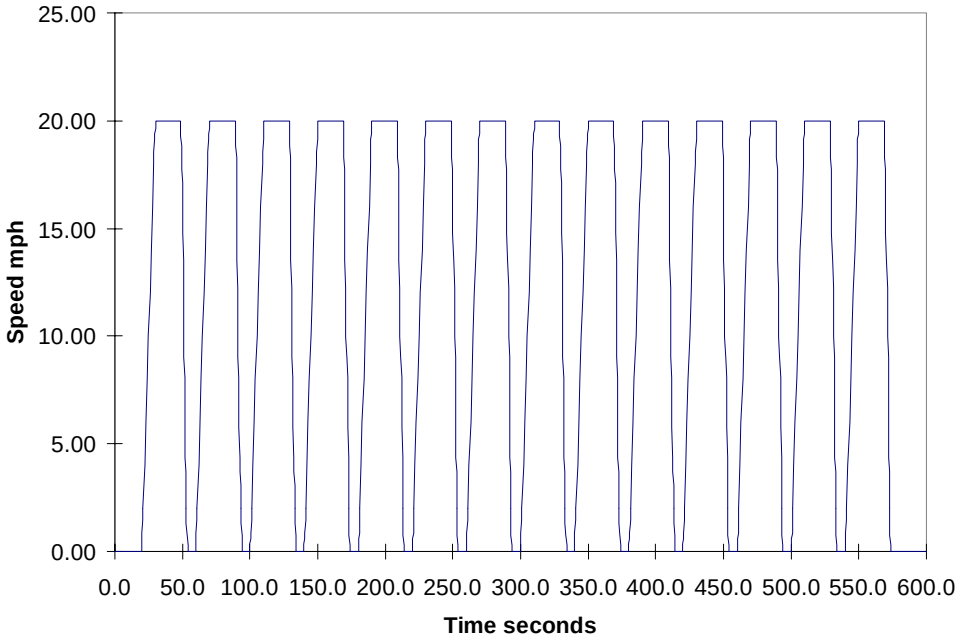
Program Outline

- Fleet demonstration *(Feb 2000 - Jan 2001)*
  - 25 Series 50 Buses; 275 Hp 1999 model year
  - Operate for 9-12 months in revenue service
  - Check back pressure and exhaust temperature
- Emissions testing *(April 2000; Feb 2001)*
  - 2 Series 50 Buses with CRT
  - Check emissions with chassis dyno under CBD & NYC Bus cycle
  - Measure at the start and at the end of program

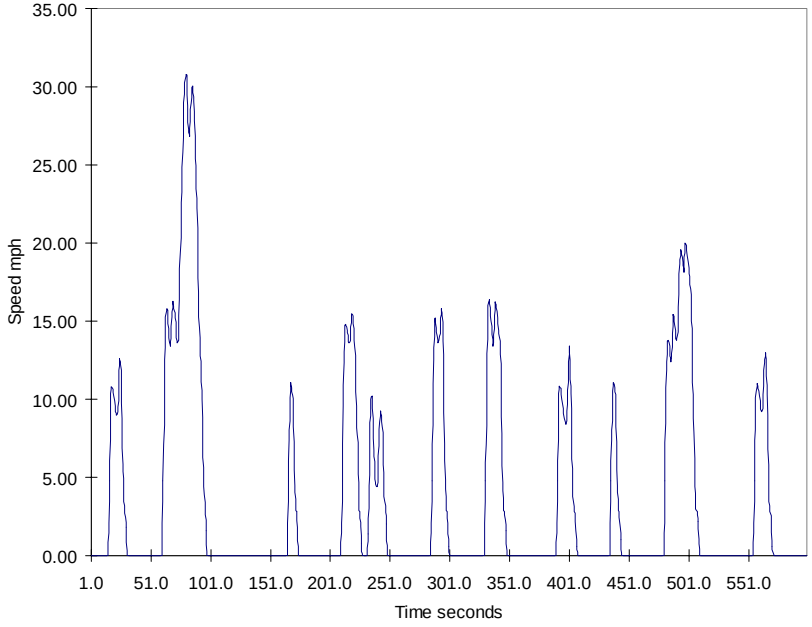
Emissions Testing

- 2 Series 50 buses tested at the beginning of the program
  - Each bus tested with OEM Catalyst/standard fuel (350 ppm S), with OEM Catalyst/ultra low sulfur fuel (30 ppm), and with CRT system/ultra low sulfur fuel (30 ppm)
- Test on chassis dynamometer using CBD and New York bus cycles
- Collect info on criteria pollutants (CO, HC, NOx, PM), plus particle size and toxicity
- Re-test both buses after 9 - 12 months of service with installed CRT filter system
- Comparison of CRT filter Data with recent CNG Test Data

Emissions Test Cycles



CBD Cycle



NY Bus Cycle

Emissions Test Procedure

In accordance with Task 2.4 of the Project Workplan for Contract No. C301293 - *A Clean Diesel Vehicle Air Quality Project*, the Emissions Research and Measurement Division of Environment Canada performed emissions testing on two Orion V 40-foot New York City Transit buses with Detroit Diesel Series 50 engines. Exhaust emissions from the buses were tested with the OE catalyst installed, with two fuels, and with a Continuously Regenerating Technology (CRT™) filter system installed. One objective of the project was to demonstrate the viability of Johnson Matthey's CRT™ filter as an exhaust after treatment technology for use in diesel fueled urban buses.

Chassis dynamometer emissions testing was performed while both buses were operated over the Central Business District Cycle (CBD) and one bus was operated over the New York Bus Cycle (NYBUS). The buses were tested in three configurations: OE with low sulfur diesel (LSD ~350 ppm sulfur), ultra low sulfur diesel (ULSD~ 30 ppm sulfur) and with the CRT™ installed. The test schedule matrix is listed in the Table below.

Configuration	**OE Muffler***		**OE Muffler***	**CRT™ Filter**	
Fuel	LSD		ULSD	ULSD	
NYCT Bus #6019	CBD**	NYBUS**	CBD	CBD	NYBUS
NYCT Bus #6065	CBD		CBD	CBD	

**OE Muffler = oxidation catalyst*
***Drive Cycle displayed on Page 3*

Emissions of carbon monoxide, carbon dioxide, oxides of nitrogen, total hydrocarbons and a calculated fuel economy were determined. Speciation of the exhaust was also determined and will be presented when analysis is complete.

The test procedures that were followed for the exhaust emission testing of these buses were outlined in the US-EPA report entitled "Recommended Practice for Determining Exhaust Emissions from Heavy-Duty Vehicles Under Transient Conditions". The exhaust emission rates and fuel economy were calculated in accordance with the US-EPA Code of Federal Regulation, Schedule 40, Part 86.

Emissions Test Procedure

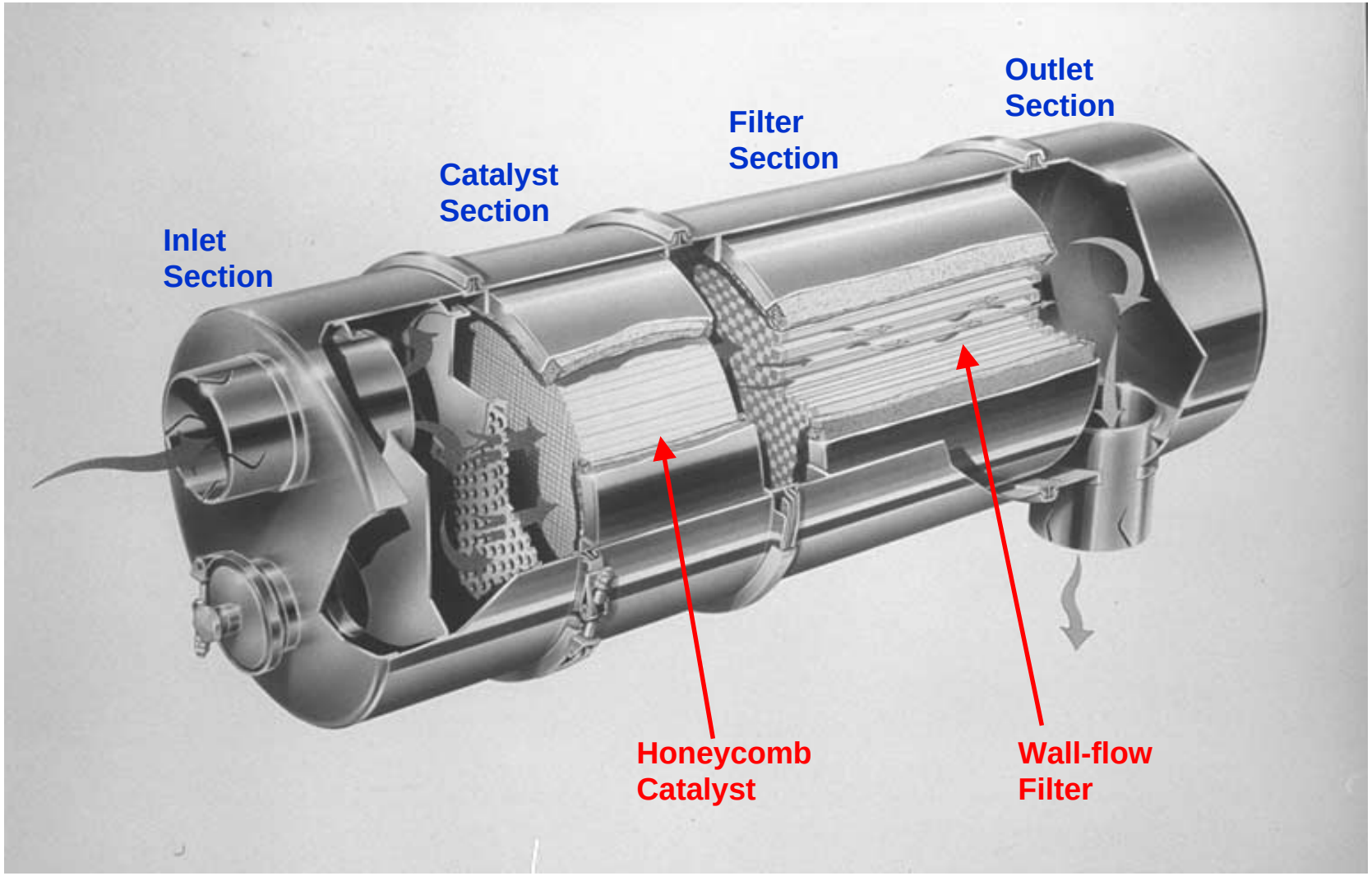
The buses were driven over a single roll chassis dynamometer system with a 0.6096m (24 inch) diameter roll. The inertia weight and road load were simulated during testing using a 400 Hp General Electric direct current motor. The system has the capability of testing vehicles from 7700 to 35000 kg (18526 to 77161 lb) while the road load is simulated at all vehicle speeds while compensating for the systems internal power losses. The buses were tested at an inertia weight of 31500 lb and a road load of 45.8 Hp.

The total exhaust stream produced by the buses was collected and diluted using a constant volume sampling (CVS) dilution system with a total dilute exhaust volume of 2000 scfm. The dilution air was taken from the test cell and was conditioned only by removal of particulate matter and volatile organics using ambient air preconditioned filters. The total volume of raw exhaust was transferred from the buses to the CVS through a six inch diameter flexible, stainless steel pipe that was insulated. The raw exhaust was then diluted with laboratory air and the mixture directed through a critical flow venturi. During the exhaust emissions test continuously proportioned samples of the dilute exhaust mixture and the dilution air were collected and stored in Tedlar® sample bags until analysis could be completed.

The stored gaseous samples were analyzed for the concentrations of total hydrocarbons (THC), oxides of nitrogen (NO_X), and carbon monoxide (CO) and carbon dioxide (CO_2), through the use of a flame ionization detector, a chemiluminescence detector, and non-dispersive infrared detectors, respectively. The dilute exhaust concentrations were then corrected for the dilution air levels and the exhaust emission rates in grams per mile were calculated. Continuous measurements of the dilute exhaust mixture were also recorded. Concentrations of nitrogen dioxide (NO_2) were determined by subtracting nitric oxide (NO) measurements from NO_X, assuming the sum of NO_X was NO plus NO_2.

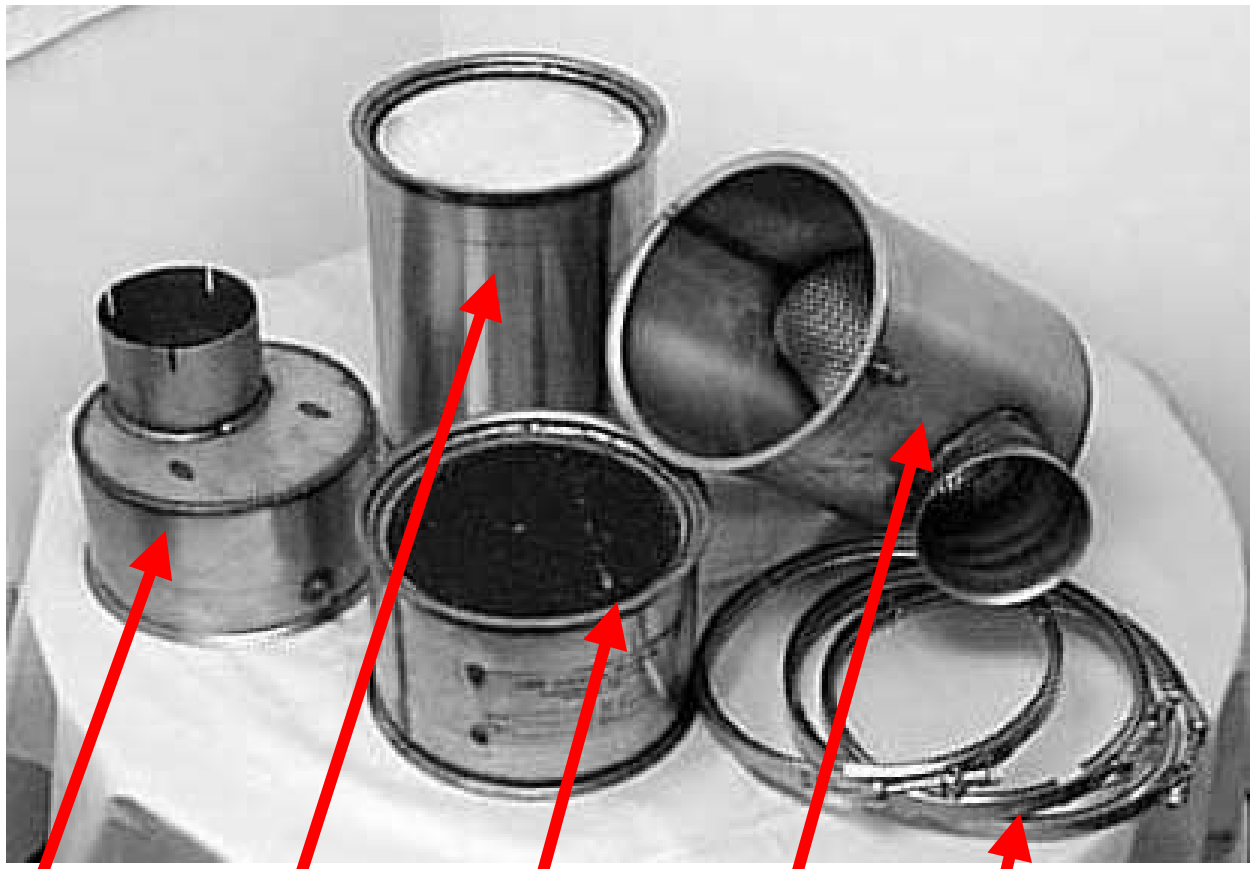
A particulate sampling system directed the exhaust through 70 mm diameter Pallflex filters (Teflon coated glass fiber) which were used to collect particulate mass from the sample stream. The filters were preconditioned in a dry chamber and their initial weight was measured. After sample collection the filters were placed in the dry chamber in order to stabilize. The filters were then re-weighed and the total particulate mass was calculated. In order to ensure adequate sample loading on the filters while testing with the CRT™ system in place, the filter was sampled over 6 repeats of the drive cycles. A dilution tunnel blank was collected over a 60 minute time period and these results were factored into the calculation of total particulate mass.

CRT™ Particulate Filter

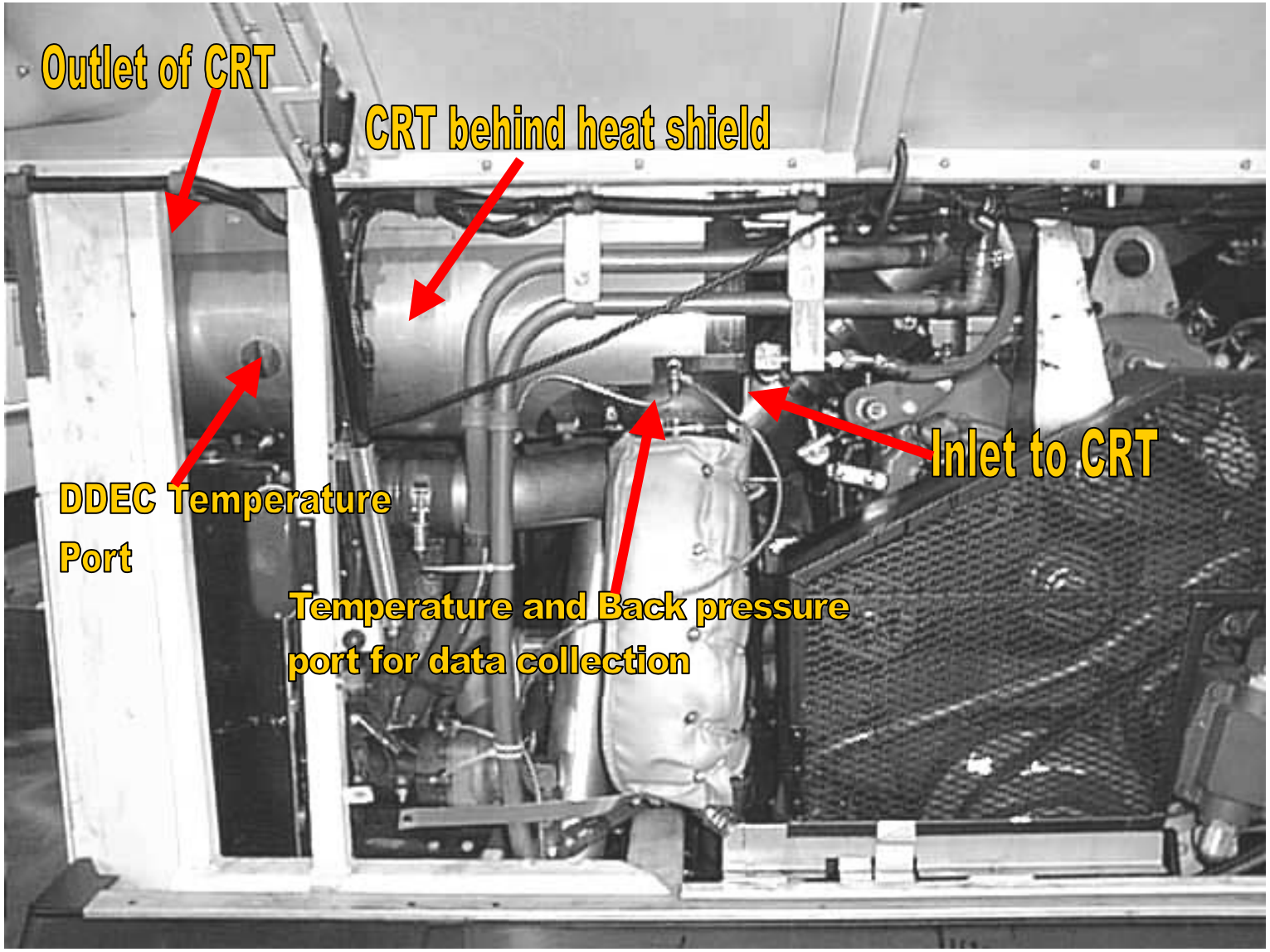


Unique Patented Johnson Matthey System

Typical CRT™ Particulate Filter



Series 50 DDEC Bus CRT™ installation



Regulated Emissions Test Results - CRT™

Bus ID	Test Cycle	Configuration	Fuel	FE (mpg)	CO2 g/mile	NOx g/mile	THC g/mile	CO g/mile	PM g/mile
NYCT #6019	CBD	OEM	LSD	3.3	2942	25.6	0.18	1.8	0.21
NYCT #6019	CBD	OEM	ULSD	3.4	2948	25.6	0.06	1.2	0.16
NYCT #6019	CBD	CRT	ULSD	3.1	3236	26.4	0.03	0.16	0.04
% Reduction Baseline to ULSD					-0.2	0.0	66.7	34.7	23.8
% Reduction Baseline to ULSD & CRT					-10.0	-3.1	83.3	91.4	82.4

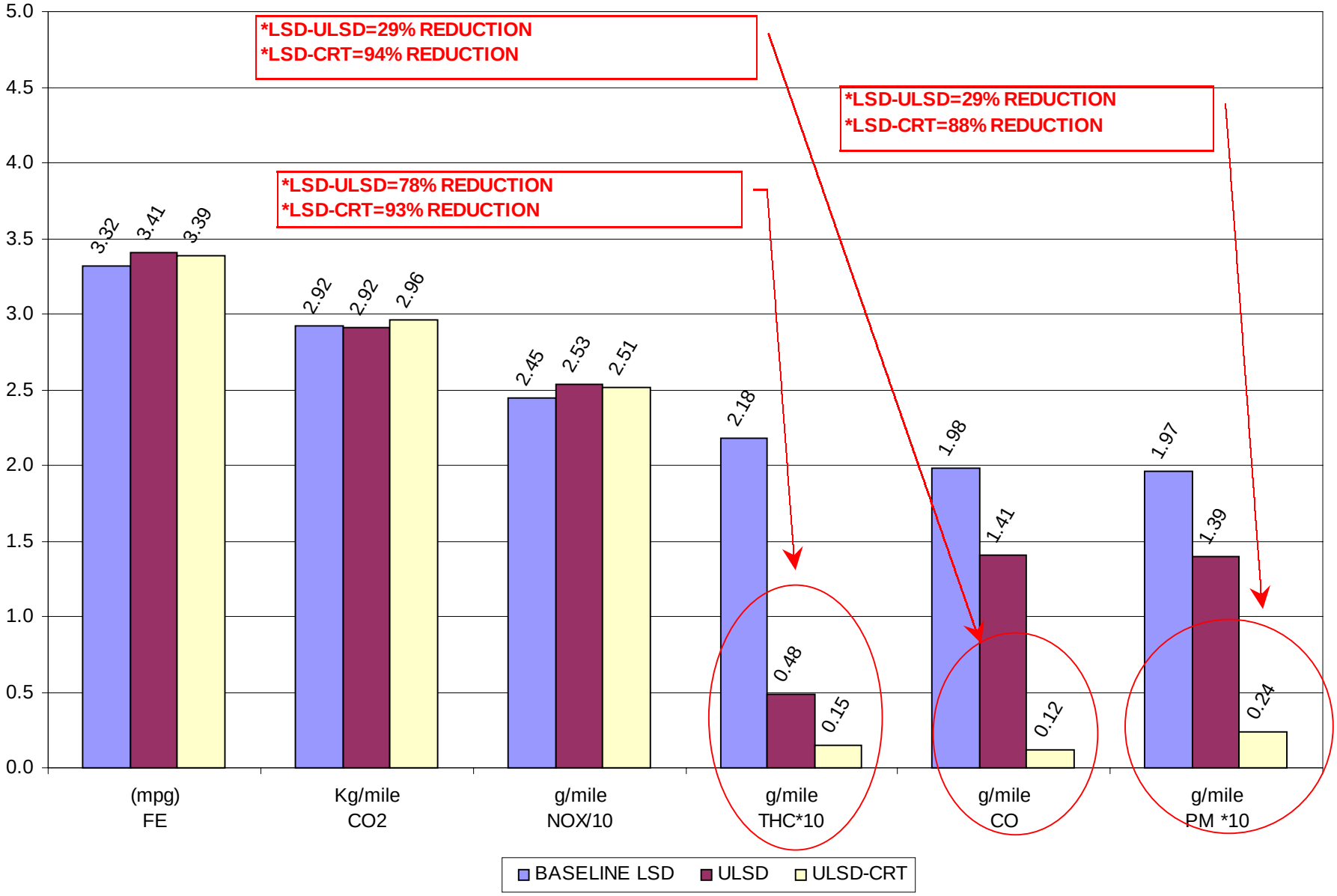
Bus ID	Test Cycle	Configuration	Fuel	FE (mpg)	CO2 g/mile	NOx g/mile	THC g/mile	CO g/mile	PM g/mile
NYCT #6019	NYBUS	OEM	LSD	1.5	6483	70.3	0.91	13	0.55
NYCT #6019	NYBUS	CRT	ULSD	1.4	7177	73.3	0.06	0.23	0.04
% Reduction Baseline to ULSD & CRT					-10.7	-4.3	93.4	98.3	93.3

Bus ID	Test Cycle	Configuration	Fuel	FE (mpg)	CO2 g/mile	NOx g/mile	THC g/mile	CO g/mile	PM g/mile
NYCT #6065	CBD	OEM	LSD	3.3	2897	23.3	0.26	2.1	0.18
NYCT #6065	CBD	OEM	ULSD	3.5	2884	25.1	0.04	1.6	0.12
NYCT #6065	CBD	CRT	ULSD	3.7	2679	23.8	0	0.09	0.01
% Reduction Baseline to ULSD					0.5	-7.6	85.7	23.9	35.0
% Reduction Baseline to ULSD & CRT					7.5	-2.1	100.0	95.9	94.0

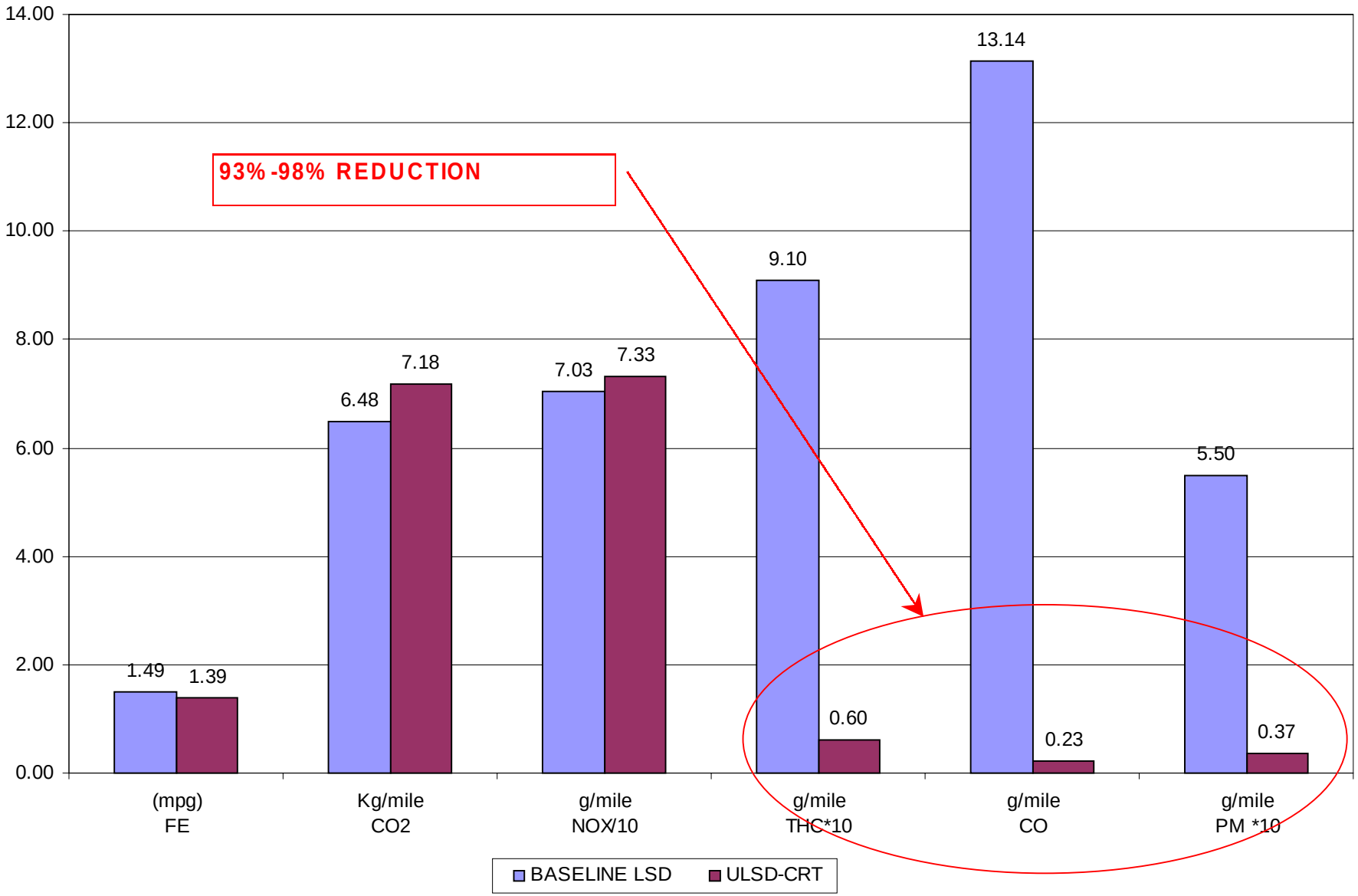
Emissions Testing Results

- ***Fuel effects:*** Going from ***Baseline LSD to ULSD*** *on the CBD Cycle* results in 76% average reduction in THC, 29% average reduction in CO, and 29% average reduction in PM
- ***CRT effects:*** *On CBD cycle**, reduction*** in Average Emissions compared to ***Baseline Fuel & Catalyst Muffler*** - 92% for THC, 94% for CO, and 88% for PM
- Emissions reductions on **NY Bus Cycle** with the **CRT** filter are even higher than on CBD: 93 - 98% Reduction in THC, CO, and PM
- The PM Emissions appear to be **independent of duty cycle** with the CRT - CO2 emissions and Fuel Economy indicate that NY Bus Cycle requires twice as much work as CBD, but there is ***NO INCREASE IN PM OUT***

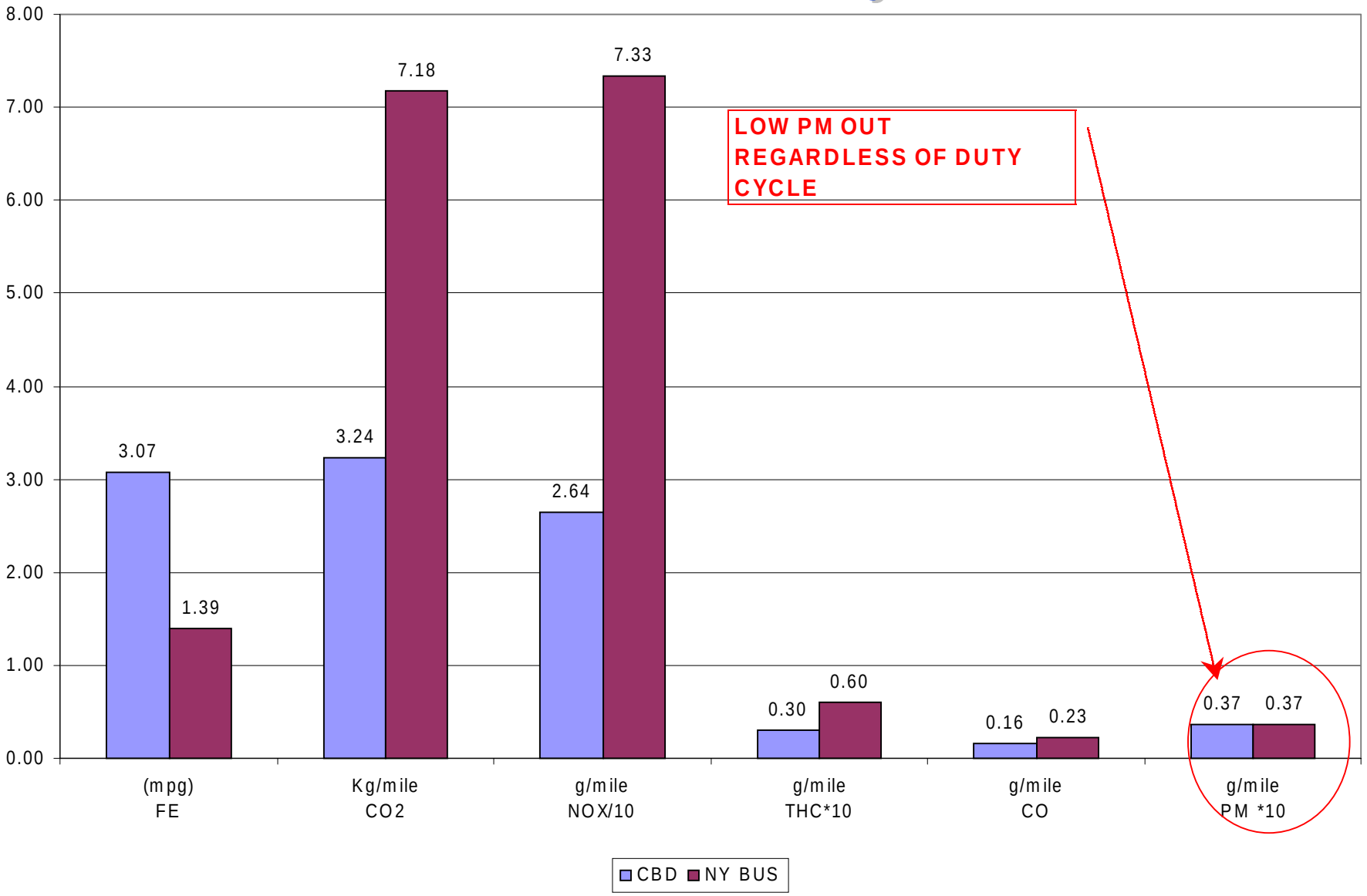
Average Series 50 Emissions Results
CBD Cycle



Series 50 Emissions Results
NY Bus Cycle



Emissions Test Results
CBD vs. NY Bus Cycle



Clean Diesel - Moving Forward

- CRT Project - Continue Durability testing until November
- CRT Project - At conclusion of durability phase, emissions test same buses
- CRT Project - Fuel matrix portion of project - explore different fuel chemistries and how they affect emissions
- CRT Project - Explore short term durability of “best” fuel chemistry from matrix
- MTA NYCT has contracted for Ultra Low Sulfur Diesel Fuel for its entire fleet for the next three years starting in September 2000
- MTA NYCT has contracted to retrofit 500 buses with CRT filters starting from September 2000

Emissions Comparison Clean Diesel vs. CNG

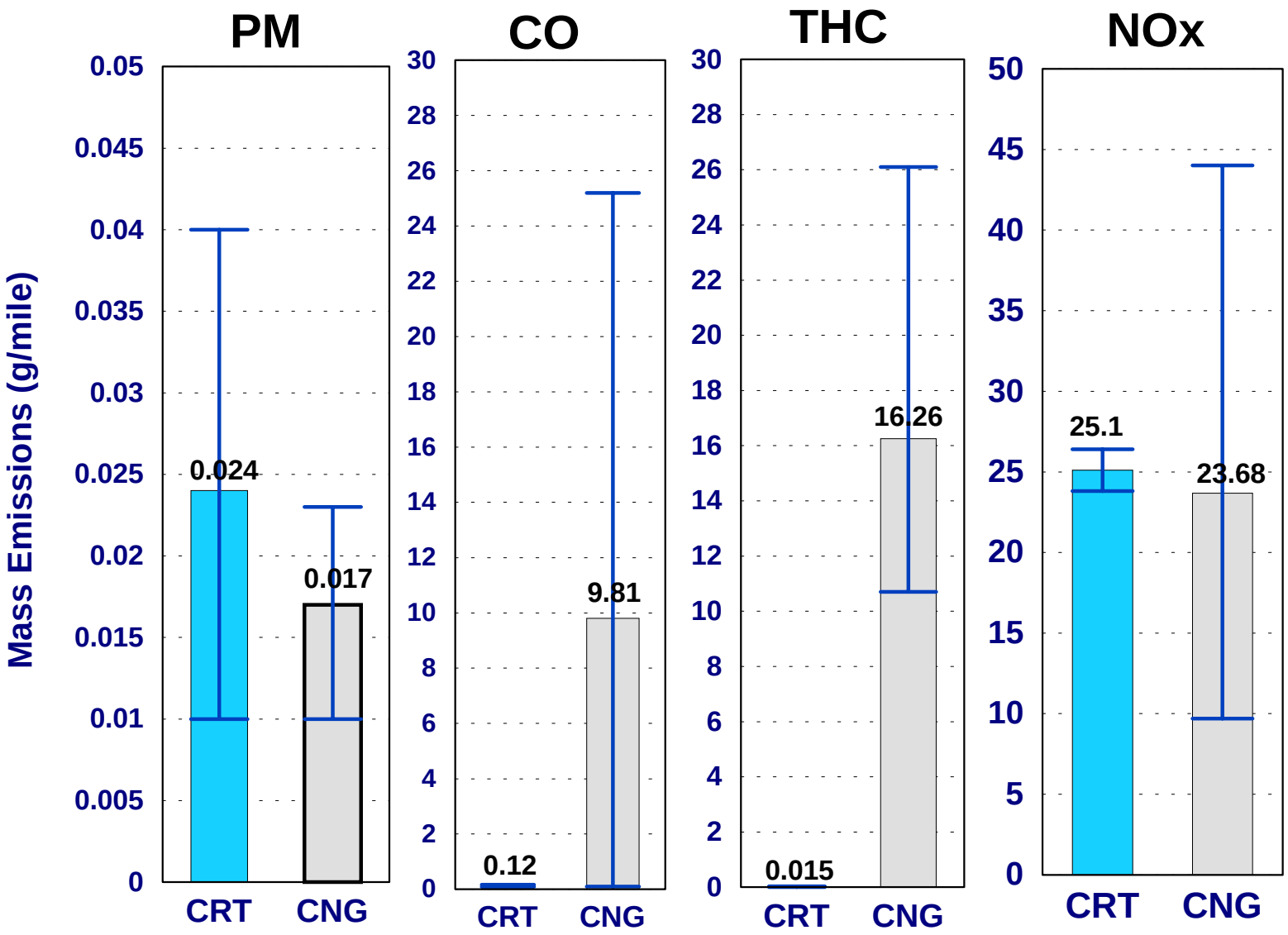
- Data on CNG emissions gathered from 3 test sites
  - CARB Testing (LA MTA)
  - NAVC Test Program (WVU)
  - NYCT Testing (Environment Canada)
- All CNG buses tested were equipped with oxidation catalysts
- CNG test data showed large variability in some emission components - for comparison to CRT, the average is shown, along with “error bars” showing the range of individual results
- In addition to regulated emissions, data is included on total CARBONYL emissions. This is a class of hydrocarbon species, primarily consisting of aldehydes and ketones. Many of these compounds such as Formaldehyde, Acetaldehyde, Acrolein and Propionaldehyde are considered very toxic and are listed in EPA’s Hazardous Air Pollutants (Title II HAP) list.

Regulated Emissions Test Results - CNG Buses

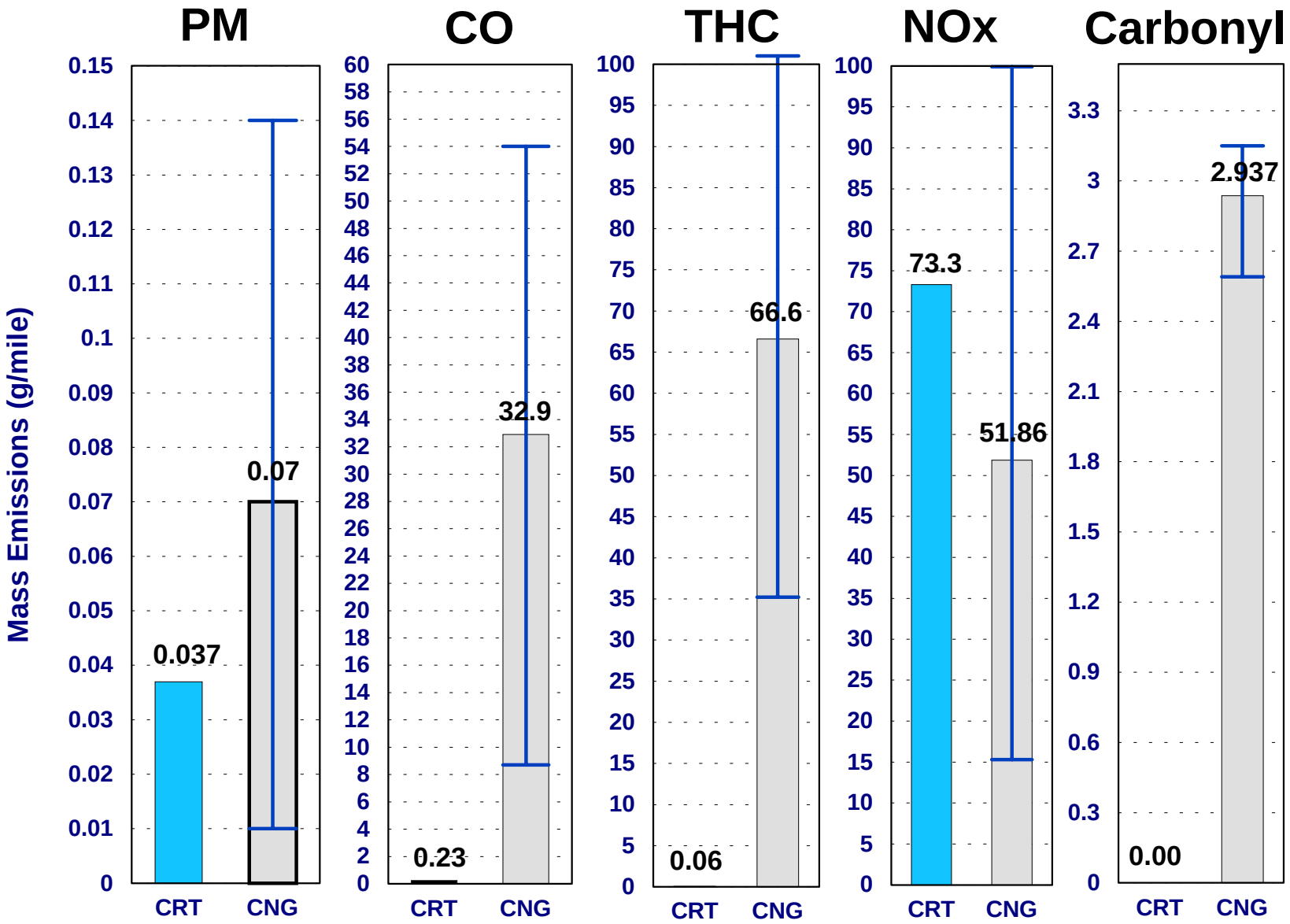
Engine Type	Bus No.	Location	Test Cycle	Test Location	F.E. (mpg)	CO2 (g/mile)	NOx (g/mile)	THC (g/mile)	CO (g/mile)	PM (g/mile)
1999 Ser 50G **	824	NYCT	CBD	Env. Canada		2112	44	19	20	0.090
1999 Ser 50G	824	NYCT	CBD	U. West Virginia	3.2	2264	15.9	23.1	12.9	0.020
1999 Ser 50G	854	NYCT	CBD	U. West Virginia	3	2421	13.8	18	12.4	0.010
1998 Ser 50G		NYDOT	CBD	U. West Virginia	2.6	2785	9.7	26.06	10.8	0.020
1998 L10G		Mass PA	CBD	U. West Virginia	3.1	2392	25	15.2	0.6	0.020
1996 L10G	4642	LAMTA	CBD	MTA/CARB	4.39	2239	27.43	10.722	25.16	0.023
1996 L10G	4740	LAMTA	CBD	MTA/CARB	3.74	2688	42.39	11.34	0.08	0.013
Average Emission			**CBD**		**3.37**	**2505**	**23.66**	**16.26**	**9.81**	**0.017**
1999 Ser 50G	824	NYCT	NY Bus	Env. Canada		5064	60	77	54	0.060
1999 Ser 50G	824	NYCT	NY Bus	U. West Virginia	1.3	5560	29.8	101	42	0.010
1999 Ser 50G	854	NYCT	NY Bus	U. West Virginia	1.3	5660	22.6	57.9	32.3	0.010
1998 Ser 50G		NYDOT	NY Bus	U. West Virginia	1.1	6535	15.3	73.34	31.7	0.110
1998 L10G		Mass PA	NY Bus	U. West Virginia		6090	113	70.24	29	0.140
1996 L10G	4642	LAMTA	NY Bus	MTA/CARB	1.9	4754	22.47	51.26		0.085
1996 L10G	4740	LAMTA	NY Bus	MTA/CARB	1.74	5696	99.89	35.15	8.67	0.105
Average Emission			**NY Bus**		**1.47**	**5623**	**51.87**	**66.56**	**32.95**	**0.074**

*** Emission data appears to be significantly different from the rest; Hence not used for average and in graphs*

Emissions Test Results - CRT vs. CNG
CBD Cycle



Emissions Test Results - CRT vs. CNG
NY Bus Cycle



Conclusion
Clean Diesel vs. CNG

- PM emissions from CRT-equipped buses appear to be equivalent to those from CNG buses
  - Average PM emissions with CNG is lower on CBD cycle, but higher on NY Bus cycle
  - Much wider range of values with CNG, especially on NY Bus cycle
- CO and HC emissions from CRT-equipped buses are much lower than those from CNG buses
- NOx emissions are generally lower from CNG buses than from CRT-equipped buses, but show a wider range of variability
- Carbonyl emissions from CNG buses are much higher than from CRT-equipped buses.